THE VALUE *of* PURE WATER

GEORGE C. WHIPPLE

THE

Value of Pure Water

BY

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"The cost of a thing is the amount of what I will call life which is required to be exchanged for it."—THOREAU

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PREFACE

"The Value of Pure Water" appeared originally in a collection of scientific papers entitled "Biological Studies by the Pupils of William Thompson Sedgwick." It has attracted an unexpected, and perhaps undeserved, amount of attention, which goes to show the popular interest in the subject. The constant demand upon the author for copies has led to its publication in the present revised form.

The author wishes to disclaim any great degree of accuracy or permanency for the formulæ suggested and to warn the reader against a too definite application of them in particular cases. The whole study is intended merely to illustrate a fact which in the past has been too little appreciated, namely, that an impure water-supply affects not only the health and comfort of a community, but also the individual pocketbooks of the people.

The financial standard is certainly not the highest one for judging the quality of a water-supply when the public health is concerned; human life cannot be estimated in gold dollars, and the smell of unsavory water to a thirsty man cannot be reckoned in dimes; nevertheless, the financial basis is a convenient one, and one necessarily involved in all questions which relate to public utilities.

To the original paper have been added a few extracts from a recent lecture delivered at the Brooklyn Polytechnic Institute on the Disadvantages of Hard Water and from an address delivered at the Annual Conference of Sanitary Officers of the State of New York on the Pollution of Streams and the Natural Agencies of Purification.

GEORGE C. WHIPPLE.

NEW YORK, January, 1907.

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THE VALUE OF PURE WATER

IN order to estimate the relative value of waters which differ materially in quality, it is necessary to have some common denominator. Nothing better for this purpose has been suggested than the dollar, which in this discussion is made the basis of computation. By ascertaining what different characteristics of water cost the consumers, and by finding out how much consumers are willing to pay to avoid using waters which possess these characteristics, an attempt has been made to secure a reasonable basis of comparison. The results of this initial study are here presented. They must not be taken too seriously at present, as some of the involved assumptions have not been established beyond doubt. With the accumulation of certain data, desirable but not as yet obtainable, the results must be somewhat

modified. Yet the general conclusions here drawn ought not to be far astray, and, from a study of the best data available, the writer believes that they err on the side of conservatism rather than on the opposite side. The suggested method of calculating the value of pure water seems to be one capable of being refined to such a degree that its results will be of great practical value. The lines along which the accumulation of data is necessary in order to render the method reliable will be evident from a perusal of the text.

Pure and Wholesome Water

To define the meaning of the expression "pure and wholesome water," which is so often found in water-supply contracts, would seem to be an easy matter, after all the study that has been given to the subject in recent years; but, although every one knows in a general way what is implied by this expression, yet when it comes to framing a definition in positive scientific terms, the problem is not as easy as it seems. This is not because the chemist and the biologist do not know what pure water is, but because water has so many attributes which have to be taken into consideration, and because these attributes vary in importance in every instance. "Pure and wholesome water" is not a substance of absolute

quality. Strictly speaking, pure water does not exist in nature; all natural waters contain substances in solution or in suspension; and in proportion as these substances are present, and in proportion as they are objectionable in character, the water is impure. Definitions of pure and wholesome water, therefore, generally state what foreign substances shall not be present, or in what amounts they are permissible, instead of defining the positive qualities which the water shall possess.

Unquestionably the term "pure and wholesome water," as ordinarily used, relates to water intended to be used for drinking. Such a water must be free from all poisonous substances, as the salts of lead; it must be free from bacteria or other organisms liable to cause disease, such as the bacilli of typhoid fever or dysentery; it must also be free from bacteria of fecal origin, such at *B. coli.* In other words, the water must be free from poisonous substances, from infection, and even from contamination.* Besides this, it must be practically clear, colorless, odorless, and reasonably free from objectionable chemical salts in solution and from microscopic organisms in suspension. Moreover, it must be well aërated. Color, turbidity, odor, dissolved salts, etc., may be permissible to a small degree without

* By this term is meant pollution with fecal matter. Contamination must be considered as potential infection.

throwing the water outside of the definition of pure and wholesome waters. In these minor matters local standards govern up to a certain point, and it is in regard to them that differences in the judgment and experience of analysts lead to diverse classifications.

When it comes to using water for other purposes than for drinking, other attributes have to be considered. Hardness makes a water troublesome to wash with and to use in boilers; iron makes trouble in the laundry; chlorine corrodes pipes and makes work for the plumbers; the presence of the carbonates and sulphates of lime and magnesia affects the paper-maker, the brewer, the tanner, the dyer, the bleacher; soda causes a locomotive boiler to foam, and affects the use of the water for irrigation. All of these constituents, and others which are not named, have to be taken into consideration in connection with a public water-supply, which may be put to any of these uses.

If it is a difficult matter to define a pure and wholesome water in strict scientific terms, it is still more difficult to compare waters which differ in purity on any reasonable basis; and yet this often has to be done. Given two water sources equally available to a city for purposes of supply, both safe to drink, but one high-colored and soft, the other colorless and hard—which is the better selection? A water-works plant is to be

appraised: structurally the system is a good one, but the quality of the water is unsatisfactory because of its excessive color or turbidity—how much should be deducted from the value of the works because of the bad quality of the water? The water-works owned by a private company are to be purchased by the city; the city has a high typhoid fever death-rate, due unquestionably to the water-supply—how much less should the city pay because of that fact? A city in the West is using turbid river water—how much can it afford to pay to filter it? A city in New England is using a water so heavily laden with Anabæna that it is nauseous to drink—how much can the city afford to pay to procure a new supply? These are all practical, every-day questions which deserve answers based on scientific data.

In valuation cases where the quality of the water-supply has been unsatisfactory, the cost of filtration, or other appropriate method of purification, has been sometimes taken as a measure of the inferior quality of the water, and this amount deducted from the value of the works. In case filtration was impractical, or more expensive than securing a supply from a new source, the additional cost of such new supply has been sometimes taken as a measure of the inferior quality of the water, and the amount deducted from the value

of the works. Both of these methods are similar in that they contemplate the substitution of a satisfactory water for one not satisfactory.

Another method of measuring the depreciation applicable to a water-works plant because of an inferior quality of the supply would be to ascertain what the use of the impure water has cost the consumers compared with what a pure and satisfactory water would have cost them. This method has not been used in practice, but it seems to be a reasonable one, and one which would be of more general application than the preceding, if the data upon which it is based could be accurately determined. Unfortunately, this is not the case in most instances, but by the use of certain generalized data and assumptions results may be secured which are of considerable use in comparing the value of waters different in quality.

The qualities of a public water-supply which most affect the ordinary consumer are:

1. Its sanitary quality; that is, its liability of infection with disease germs or substances deleterious to health.

2. Its general attractiveness, or lack of attractiveness, as a drinking-water.

3. Its hardness, so far as this relates to the use of soap in the household.

4. Its temperature, so far as this relates to drinking.

Characteristics which affect industrial uses are too much a matter of local concern to be taken into account in a general discussion, although they are by no means of small account, and in some communities their importance might control. These are referred to on a later page. The qualities selected are to be considered as illustrative of the method rather than as a complete exposition of it.

Sanitary Qualities

If the water under consideration has been used for a considerable time, the typhoid-fever death-rate of the community will fairly well represent the sanitary quality of the water-supply. It will not tell the whole story, but in most cases it will not lead far astray. In order to reduce this to a financial basis, it is necessary to make several assumptions.

The financial value of a human life is generally taken as $5,000, but according to Leighton * it varies at different ages from $1,000 to $7,000, as shown by Table

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* M. O. Leighton, *Popular Science Monthly*, January, 1902.

1. It so happens that persons are most susceptible to typhoid fever near the age when their life-value is considered greatest. By combining the life-value at different ages with the age distribution of persons dying of typhoid fever, the resulting average value of persons dying from typhoid fever is found to be $4,635, which is very close to the figure ordinarily used.

The percentage mortality of typhoid-fever patients is sometimes stated as 10 per cent; that is, ten cases for every death. Figures of this character are most often based on hospital records, and mild cases do not generally reach the hospitals. Studies of recent typhoid epidemics indicate that 15 to 18 cases for each death would be nearer the truth. The expense of medical treatment, nursing, and medicine, the loss of wages for a month or more, together with other attending expenses and inconveniences, would doubtless aggregate at least $100 per case, or $1,000 for the 10 cases corresponding to one death. If the estimate of $100 is considered too large, it may be answered that the excess is more than offset by the fact that there are more often from 15 to 18 cases for each death than there are 10. It may be fairly assumed, therefore, that $6,000 is a very moderate estimate of the financial loss to the community from typhoid fever for each death from that disease.

TABLE 1.

Age.	Estimated value of human life.	Per cent of deaths from typhoid fever.	Product of columns 2 and 3.
0– 5 years.....	$1,500	5.0	7,510
5–10 "	2,300	5.9	13,570
10–15 "	2,500	7.2	18,000
15–20 "	3,000	13.1	39,300
20–25 "	5,000	16.7	83,500
25–30 "	7,500	13.2	99,100
30–35 "	7,000	9.9	69,300
35–40 "	6,000	8.0	48,000
40–45 "	5,500	5.6	30,900
45–50 "	5,000	4.0	20,000
50–55 "	4,500	3.3	15,000
55–60 "	4,500	2.6	11,700
60–65 "	2,000	2.1	4,200
65–70 "	1,000	1.5	1,500
70 "	1,000	1.9	1,900
Total.....	....	100.00	$463,480

Average value of life of persons dying from typhoid fever, $4,635.

Typhoid fever is by no means the only disease transmitted by contaminated water. Dysentery and various other diarrheal diseases precede it or follow in its train, and in most instances these are probably due to the same general sources of contamination as those which caused the typhoid fever, although, of course, to different specific infections. The reduction of the typhoid-fever death-rate following the substitution of a pure water for a contaminated water is often accompanied by a drop in the death-rate from other diseases. Thus, if the five years before and after filtered water was intro-

TABLE 2.

EFFECT OF FILTRATION ON DEATH-RATES AT ALBANY, N. Y., AND A COMPARISON WITH TROY, N. Y., WHERE THE WATER WAS NOT FILTERED.

	Death-rates per 100,000.			Per cent reduction of death-rates.
	1894–98, before filtration at Albany.	1900–04, after filtration at Albany.	Decrease.	
ALBANY				
Typhoid fever.........	104	26	78	75
Diarrheal diseases.....	125	53	72	57
Children under 5 years..	606	309	297	49
Total deaths......	2,264	1,868	378	17
TROY				
Typhoid fever.........	57	57	0	0
Diarrheal diseases.....	116	102	14	12
Children under 5 years..	531	435	96	18
Total deaths......	2,157	2,028	129	6

Remark.—Filtered water was introduced into Albany in 1899. The water-supply of Troy has remained practically unchanged.

duced into Albany, N. Y., are compared, it will be seen that the reductions in deaths from general diarrheal diseases and the deaths of children under five years of age were much greater than in the case of typhoid fever. There was also a reduction in malaria, but this probably represents faulty diagnosis of typhoid-fever cases before

the introduction of filtered water rather than a real reduction of malaria. That the reduction of infant mortality and deaths from diarrheal diseases was not due to other conditions seems probable, from the fact that in the neighboring city of Troy, where the water-supply was not changed, there was no such diminution during the same period.

Hazen, in his paper on "Purification of Water in America," read at the International Engineering Congress at St. Louis, called attention to this same fact, that after the change from an impure to a pure supply of water the general death-rate of certain communities investigated fell by an amount considerably greater than that resulting from typhoid fever alone—indicating either that certain other infectious diseases were reduced more than typhoid fever, or that the general health tone of the community had been improved. Thus, for five cities where the water-supply had been radically improved he found:

	Per 100,000.
Reduction in total death-rate in five cities with the introduction of a pure water-supply	440
Normal reduction due to general improved sanitary conditions, computed from average of cities similarly situated, but with no radical change in water-supply	137
Difference, being decrease in death-rate attributable to change in water-supply	303
Of this, the reduction in deaths from typhoid fever was	71
Leaving deaths from other causes attributable to change in water-supply	232

From these facts it is evident that to place the financial loss to a community as $6,000 for each death from typhoid fever due to the public water-supply is to use too low a figure. It probably ought to be several times as high; but recognizing the lower financial value placed on the lives of infants, and the less serious character of the other diseases, and wishing to be as conservative as possible, for the reason that typhoid fever is not entirely a water-borne disease, $10,000 per typhoid death has been used in the calculation which follows.

Since typhoid fever is a disease which may be transmitted in other ways than by water (as, for instance, by milk, raw fruit, shell-fish, or flies), it is necessary to allow a certain death-rate for these other causes, for even in a city where the water-supply is perfect there may be still some typhoid fever. This has been sometimes called "residual typhoid." To establish this residual, or "normal," * is a difficult matter, but for purposes of calculation we may assume it to be determined and represent it by the letter N.

If we assume that all typhoid fever in excess of N is due to the water-supply, and if we assume that the daily consumption of water is 100 gallons per capita,

* This term "normal" must not be assumed to mean *necessary* typhoid.

then, letting T equal the typhoid-fever death-rate per 100,000,

$(T-N)$ 10,000 = loss to the community in dollars for $365 \times 100 \times 100{,}000$ gallons of water, or $D=\frac{(T-N)1{,}000}{365}$ $=2.75(T-N)$,
where D stands for the loss in dollars per million gallons of water used.

Suppose the average typhoid-fever death-rate for a community which has a somewhat polluted water-supply has averaged 43 per 100,000 for a period of five years, and suppose that for this place the value of N is estimated as 15, then

$D=2.75\ (43-15)=\$76.72$, if the per-capita consumption is 100 gallons. If the consumption per capita is 115 gallons, D would be $\frac{100}{115}$ of \$76.72, or \$66.71; if it were 63 gallons per capita, then D would equal $\frac{100}{63}$ of \$76.72, or \$121.77.

The value of N must be naturally subject to local variation, and in order to obtain an idea as to its probable value, a compilation of typhoid-fever death-rates has been made for cities and towns in different parts of the country which use ground waters or filtered waters—that is, waters which may be considered as free from contamination.

The following is a generalized summary of them.

TABLE 3.

TYPHOID-FEVER DEATH-RATES IN CITIES AND TOWNS WHICH HAVE GROUND-WATER SUPPLIES.

State.	Number of cities and towns averaged.	Number of years averaged.	Average typhoid-fever death-rate per 100,000.
Maine	2	5	6.4
Massachusetts	23	5	15.8
Conne ticut	4	5	9.5
New York	13	5	24.7
New Jersey	10	1	20.5
Pennsylvania	5	1	31.8
Ohio	22	5	32.4

There is reason to believe that the higher rates given above do not correctly represent the situation, because in some instances the ground-water was supplemented by the occasional use of water which may have been polluted. Proximity to a large city where the water-supply is contaminated was also responsible for some of the high figures; so also was the absence of sewerage systems. Nevertheless, there seems to be a marked tendency for the typhoid-fever rates to increase in the United States from north toward the south in those places where the water-supply is reasonably safe. There are some exceptions to the increase southward, however. Thus, in Camden, N. J., which is supplied with a pure ground-water, the typhoid rate was only 12 in 1901 and 20 in 1902. Washington is a city which has

a large amount of typhoid fever due to causes other than water. Here the value of N is over 30.

In Fuertes' book on *Water and the Public Health* * a diagram is given showing that the typhoid-fever death-rates in cities supplied with ground-water vary from 5 to 32 per 100,000 in America, and from 6 to 33 per 100,000 in Europe, the average being about 18 in America and 19 in Europe. It is shown also that the death-rates from cities supplied with filtered water vary from 4 to 20 in America, and from 4 to 20 in Europe, the average being 12 in both cases. Recent American data for cities supplied with filtered water show that the rates are somewhat higher than these, the average being somewhat less than 20.

Taking into consideration the best available data, it seems reasonable to place the general value of N somewhere between 10 and 25 per 100,000, with the most probable average value as 20, which figure may be used in the equation where local sanitary conditions are unknown. The value of N, however, should be varied where there is reason for doing so. Where the sanitary conditions are good, 15 may be taken as a fair value. In New England it might be placed lower than in regions south of the glacial drift; in cities near the seaboard,

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* *Water and the Public Health*, by James H. Fuertes, John Wiley & Sons, New York, 1901.

where there is a large consumption of oysters taken fresh from the layings, the value of N might be higher than in inland cities, where the oyster consumption is small and where fattened oysters are not used as freely; in cities where there are cesspools but no sewers, the value of N would naturally be higher than in cities well provided with sewers.

It may be reasonably expected that, as time goes on, the value of N will gradually fall, because of a general decrease of typhoid fever in the country at large, and a consequent diminution of the number of foci of infection. Statistics for twelve States, including all the New England States, New York, New Jersey, Maryland, California, Minnesota, and Michigan, show that during the last quarter of a century the general typhoid-fever death-rate has fallen as follows:

TABLE 4.

	Average typhoid-fever death-rate per 100,000.
1880	55
1885	46
1890	36
1895	28
1900	23
1905	21

Attractiveness

The analytical determinations which relate to the general attractiveness of a water are those of taste, odor,

color, turbidity, and sediment. As these quantities increase in amount, the water becomes less attractive for drinking purposes, until finally a point is reached where people refuse to drink it. In order to use these results in a practical way, it is necessary to combine them so as to obtain a single value for the physical characteristics or, as they say abroad, for the "organoleptic" quality of the water. An attempt has been made by the author to obtain what may be termed an æsthetic rating of the water, and the result is shown in the diagram on page 18.

This diagram, it should be said, is based almost entirely upon estimates and very little upon statistical data. It rests upon the assumption that people differ in their sensibilities or their æsthetic feelings as to the use of water. Some persons are much more fastidious than others in regard to what they drink. A water which would be shunned by one person, even though he were thirsty, might be taken by another with apparent relish. As a rule, people are more fastidious about the odor of water and the amount of coarse sediment which it contains than they are about its color and turbidity. This is perhaps natural, as a bad odor suggests decay, and decay is instinctively repugnant. Often, however, people do not discriminate between odors which are due to decomposition and those which

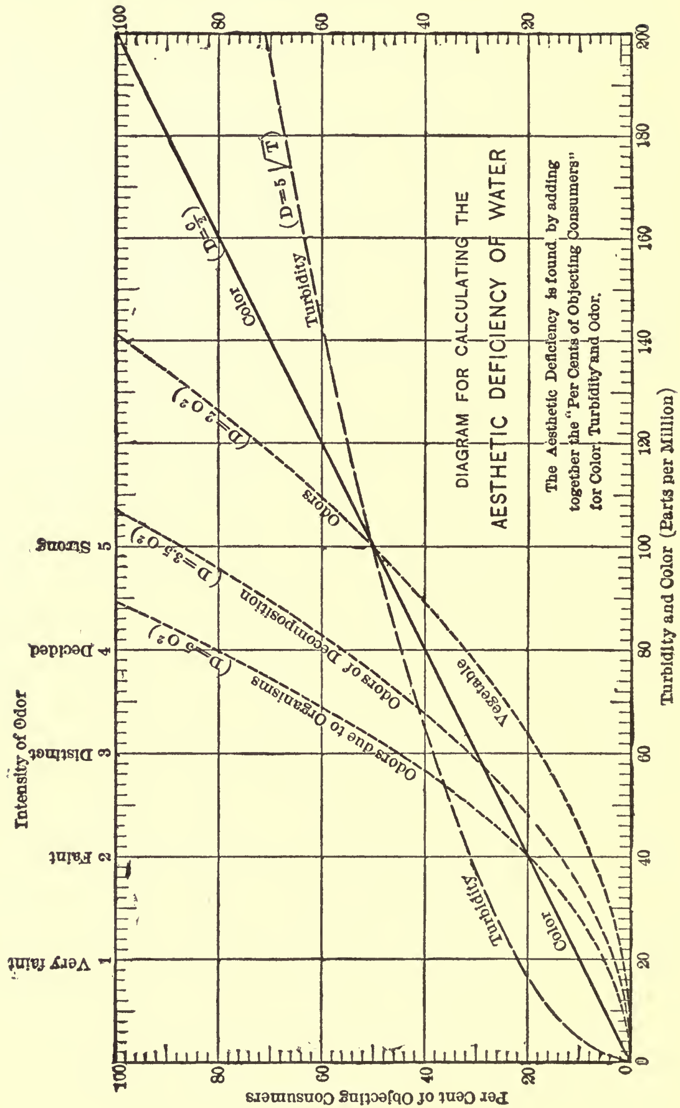
DIAGRAM FOR CALCULATING THE
AESTHETIC DEFICIENCY OF WATER
The Aesthetic Deficiency is found by adding together the "Per Cents of Objecting Consumers" for Color, Turbidity and Odor.
Turbidity and Color (Parts per Million)
Per Cent of Objecting Consumers
Intensity of Odor
Very faint
Faint
Distinct
Decided
Strong
Color
Turbidity
Odors
Vegetable
Odors of Decomposition
Odors due to Organisms

are not. Habit and association have much to do with a person's views as to the attractiveness of water. In New England, where the clear trout brooks run with what Thoreau called "meadow tea," few people object to a moderate amount of color, while they do object to a water which is very turbid. In the Middle West, where all the streams are muddy, it is the unknown colored waters which are disliked. People who are accustomed to well-water object to both color and turbidity. With most people a fine turbidity, such as is produced by minute clay particles, is less a subject of complaint than an equal turbidity produced by comparatively coarse sediment. In the diagram an attempt has been made to reconcile these different points of view, so as to put them, as well as may be, on the same footing. In this connection several series of comparisons were made.* Turbid waters were viewed by a group of Western people, who made some comparisons with colored and turbid waters, while colored waters were viewed by a group of students in New York, and *vice versa*.

The abscissæ of the diagram represent turbidity, color, and odor, as given in the ordinary water analy-

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* Acknowledgments are due to Mr. J. W. Ellms, of Cincinnati, Ohio, and Mr. Andrew Mayer, Jr., of Brooklyn, N. Y.

sis.* The ordinates represent the "per cent of objecting consumers." By this is meant the proportion of the water-takers who would ordinarily choose not to drink the water because of the quality indicated by the curve, or who would buy spring water, or bottled water, rather than use the public supply, if they could afford to do so. This number would increase, of course, as the general attractiveness of the water decreased. From the curves one may calculate what may be called the *æsthetic deficiency* of the water by adding together the per cents of objecting consumers for color, turbidity, and odor. If the æsthetic deficiency equals 100, it indicates that the water is of such a character that every one would object to it, and figures in excess of 100 only emphasize its objectionable character.

It will be seen from the diagram that when the color of water is less than 20, or the turbidity less than 5, only one person in ten would object to it, but when the turbidity or color is 100, one-half of the people would object to it. It may be thought that this proportion is too low, but it must be remembered that colored waters are invariably accompanied by a vegetable odor and often by a slight turbidity, and that it is the sum of the several quantities which determines the æsthetic rating.

* See "Report of Committee on Standard Methods of Water Analysis, American Public Health Association," Supplement No. 1, *Journal of Infectious Diseases*, May, 1905.

Experience has shown that objection to color varies directly with its amount; consequently this curve has been plotted from the equation, $p_c = \frac{c}{2}$, i.e., a straight line, where p_c stands for the per cent of objecting consumers, and c for the color.

In the case of turbidity, however, small amounts count for more, relatively, than larger amounts. The equation for the turbidity curve has been taken, therefore, as $p_t = 5\sqrt{t}$, where t stands for the turbidity.

With odor, however, the opposite condition prevails; faint odors count for little, but distinct and decided odors cause much more complaint. Consequently, the per cent of objecting consumers has been made to vary as the square of the intensity of the odor expressed according to the standard numerical scale. The quality of the odor makes quite as much difference as its intensity, and for that reason three curves have been plotted, one representing vegetable or pondy odors (O_v), one representing odors due to decomposition (O_d), and one representing the aromatic, grassy and fishy odors due to microscopic organisms (O_o). These curves are plotted from the following equations:

$$p_o = 5O_o^2,$$

$$p_o = 3.5O_d^2,$$

$$p_o = 2O_v^2,$$

in which O_o, O_d, and O_v stand for the intensity of the three groups of odors mentioned.

These curves represent somewhat imperfectly our present ideas as to the relative effects of color, turbidity, and odor; and on further study they are likely to be considerably modified.

It is a well-known fact that in cities which are supplied with water which is not attractive for drinking purposes, large quantities of spring water and distilled water are sold, and that consumers go to much expense in the purchase of house-filters in order to improve the quality of the water furnished by the city mains. It is fair to assume that in any community the amount of money expended for bottled water and house-filters will vary in a general way, according to the attractiveness of the water, although there is no doubt that the presence of typhoid fever in the community, or the fear that the water is contaminated, will greatly increase the use of auxiliary supplies for drinking. For purposes of calculation it may be assumed that the diagram just described represents this tendency to use vended waters, and that each "objecting consumer" would go to the expense of buying spring-water or putting in a house-filter, if he could afford it. It may be argued, also, that the poor consumer who may be un-

able to do this is as much entitled to satisfactory water as is the well-to-do consumer.

From a study of price-lists of spring-waters sold in New York and other cities, it has been found that the ordinary wholesale price of spring-water is seldom more than 10 cents a gallon. In some places it is as low as 1 cent. The average is about 5 cents. To filter water through house-filters costs less, but generally it is less satisfactory.

As a convenient figure for calculation, and as a most conservative one for general use, a cost of 1 cent per gallon to the ordinary consumer for an auxiliary supply of drinking-water (either spring-water or well-filtered water) has been taken. In cities where the cost of procuring and distributing bottled water exceeds 1 cent per gallon, as it does in such a city as New York for example, this should be taken into account in making local use of the data. For the illustrative purposes of the present study, and for general comparisons, the figure mentioned will serve as a satisfactory basis. The average person drinks about 1.5 quarts of liquid per day, of which one-half may be assumed to be water, the rest being tea, coffee, etc. Therefore one-fifth cent per capita daily may be taken as a reasonable figure for the cost of an auxiliary supply. If the entire population used such a supply, and if the daily consumption

of the public water-supply were 100 gallons per capita, then one-fifth cent per hundred gallons, or $20 per million gallons, would represent the loss to the consumers due to an imperfect water-supply which had an æsthetic deficiency of 100. If the æsthetic deficiency were less than 100, say 37, then the loss to the consumer would be $\frac{37}{100}$ of $20, or $7.40 per million gallons. In other words, the figure for the æsthetic deficiency divided by 5 gives the financial depreciation of the water-supply in dollars per million gallons, or

$$D = 20\frac{p_c + p_t + p_o}{100}.$$

Example: Suppose the turbidity of a water is 3, its color 65, and its odor 2*f* (that is, faintly fishy), because of the presence of microscopic organisms; then $D = 20\frac{12+32+20}{100} = \$12.80$; that is, the depreciation of the water, because of its unsatisfactory physical qualities, amounts to $12.80 per million gallons.

Hardness

The point at which a water becomes objectionably hard has never been exactly defined. Standards of hardness vary in different parts of the country. The ordinary person washing his hands considers the water

soft if the soap will quickly produce a suds without curdling. A hardness of 10 parts per million is practically unnoticeable, and it requires a hardness of 20 or 30 parts per million to produce "curdling." Waters which have a hardness below 25 parts per million seldom cause much complaint, but when the hardness rises above 50 the water is well entitled to the appellation "hard," and above 100 it may be called very hard. In some parts of the country hardnesses of 200 or 300 are observed; these may be termed "excessive."

In 1903 a number of experiments were made by the author to determine the effect of various degrees of hardness on the amount of soap produced in washing the hands, in bathing, and in general household uses. These showed that the hardness of the water had a substantial effect on the use of soap. Tests were also made with eight of the common soaps and washing powders on the market, to determine how much of the average soap used in a household it would take to completely soften waters of different degrees of hardness. Comparative figures were also obtained for the standard Castile soap commonly used in the laboratory making the soap test for hardness. The results of these experiments are given in Table 5.

TABLE 5.

TABLE SHOWING THE RELATION BETWEEN THE HARDNESS OF WATER AND THE AMOUNT OF SOAP REQUIRED TO SOFTEN IT.

Hardness (parts per million).	Number of c.c. of standard soap solution for 50 c.c. water.	Number of grams of standard soap per gallon of water.	Number of gallons of water softened by one pound of									
			Standard Castile soap.	Ivory soap.	Babbitt's laundry soap	Sapolio.	Bon ami.	Gold dust.	Pearline.	Pears's hand soap.	Colgate's cerosa toilet soap.	Average (omitting the standard Castile soap.)
20	2.1	1.11	409	196	138	102	143	165	167	187	225	167
25	2.4	1.27	358	174	121	90	125	145	147	164	206	147
40	3.6	1.91	238	115	80	59	83	96	98	109	137	97
50	4.3	2.28	200	96	67	50	70	81	82	92	115	82
75	6.1	3.24	140	67	47	35	49	57	58	64	80	57
80	6.4	3.49	130	70	44	33	45	52	53	60	75	54
100	7.8	4.13	110	53	37	27	38	44	45	50	63	45
125	9.5	5.04	90	43	30	25	31	36	37	41	52	37
150	11.1	5.89	77	37	26	19	27	31	32	35	44	31
175	12.7	6.74	67	32	23	17	23	27	28	31	38	27
200	14.3	7.59	60	29	20	15	21	24	25	27	34	24

It was found that one pound of the average soap would soften 167 gallons of water which had a hardness of 20 parts per million. This is equivalent to about three tons of soap per million gallons. It was also found that for every increase of one part per million of hardness the cost of soap increased about $10 per million gallons of water completely softened. The following table shows the way in which this amount was calculated.

TABLE 6.

TABLE SHOWING THE AVERAGE COST OF SOFTENING WATER BY SOAP.

Hardness (parts per million).	Average number of gallons of water softened by one pound of average soap.	Number of pounds of soap required to soften one million gallons of water.	Increase in hardness above 20 parts per million.	Increase in number of pounds of soap required to soften one million gallons of water.	Increase in number of pounds of soap required to soften one million gallons of water for each part per million increase in hardness.	Increase in cost of soap per million gallons for each part per million of hardness at 5 cents per pound.
20	167	5,990				
25	147	6,810	5	820	164	$ 8.20
40	97	10,300	20	4,310	215	10.75
50	82	12,200	30	6,210	207	10.35
75	57	17,500	55	11,510	209	10.45
80	54	18,500	60	12,510	209	10.45
100	45	22,200	80	16,210	203	10.15
125	37	27,100	105	21,110	200	10.00
150	31	32,200	130	26,210	202	10.10
175	27	37,100	155	31,110	201	10.05
200	24	41,700	180	35,710	199	9.95
		Average	......	....	201	$10.05

All of the water used by a community is not completely softened. The number of gallons per capita per day completely softened has been estimated by different authorities all the way from 1 to 10. It will certainly be a conservative estimate to assume that one gallon per capita is thus softened. On this basis the depreciation of water, on account of its hardness, is $D = \frac{H}{10}$, in which H equals the hardness of the water in parts per million, and D the depreciation in dollars per million gallons.

Example: Assume the total hardness of a water to be 79 parts per million; then $D=\frac{79}{10}=\$7.90$ per million gallons.

This takes into account only the cost of soap used for domestic purposes, and does not include the incidental losses and inconveniences attendant upon the use of hard water in the household. These, if they could be expressed in terms of dollars and cents, would probably more than equal the cost of soap; therefore the above figures err on the side of conservatism.

Temperature

Every one knows that warm water is unpalatable. When the temperature rises above 60° F., people do not like to drink it without cooling. The relation between the temperature of the water and the per cent of objecting consumers may be represented by a curve based on the equation $p=\frac{(d-45)^2}{9}$, in which p equals the per cent of objecting consumers, and d equals the temperature of the water in Fahrenheit degrees. According to this formula, no one would object to drink a water which had a temperature of 45°, half the people would object at 66°, and all would object at 75°. If it is assumed that it takes one-half pound of ice per capita daily to

cool the water used for drinking during four months in the year, and that ice costs 30 cents per 100 pounds, then the depreciation due to temperature would be equivalent to \$5 per million gallons of public supply for 100 per cent of objecting consumers, assuming the per-capita consumption to be 100 gallons daily, or $D=\frac{p}{100}\times\$5=\frac{(d-45)^2}{180}$ in dollars per million gallons, in which d = the average temperature during the four warmest months of the year. This may be considered as the depreciation due to temperature. The temperature of ground-water seldom rises above 60° in the house-taps even in summer, and in cities supplied with ground-water a large proportion of the consumers do not use ice. Surface-waters, on the other hand, in the latitude of New York, generally maintain a temperature of 60° or more at the house-taps for at least four months of the year. The temperature factor is an important one in many cases, but it need not be used except when comparing surface-waters with ground-waters.

In a similar way it might be possible to calculate the reduced value of a water due to other objectionable characteristics, such as the presence of large amounts of iron or chlorine. Except in special cases, these would not be as important as the more obvious quali-

ties above described, and they need not be considered in this discussion.

Summary of Principal Formulæ

Depreciation due to sanitary quality:

1. $D = 2.75(T - N)$.

Depreciation due to physical characteristics:

2. $D = 20\dfrac{p_c + p_t + p_o}{100}$

$$p_c = \frac{c}{2}$$

$$p_t = 5\sqrt{t}$$

$$p_o = 2O_v^2 + 3.5O_d^2 + 5O_o^2$$

Depreciation due to hardness:

3. $D = \dfrac{H}{10}$.

Depreciation due to temperature:

4. $D = \dfrac{(d - 45)^2}{180}$, in which

D = the depreciation in dollars per million gallons;

T = typhoid-fever death-rate per 100,000;

N = typhoid-fever death-rate assumed to be due to causes other than water, and which may be ordinarily taken as 20 per 100,000;

TABLE 7.

DEPRECIATION DUE TO SANITARY QUALITY.

Values of D for different values of T-N in the formula $D=2.75(T\text{-}N)$. Dollars per million gallons.

T-N	0	1	2	3	4	5	6	7	8	9
0	0.00	2.75	5.50	8.25	11.00	13.75	16.50	19.25	22.00	24.75
10	27.50	30.25	33.00	35.75	38.50	41.25	44.00	46.75	49.50	52.25
20	55.00	57.75	60.50	63.25	66.00	68.75	71.50	74.25	77.00	79.75
30	82.50	85.25	88.00	90.75	93.50	96.25	99.00	101.75	104.50	107.25
40	110.00	112.75	115.50	118.25	121.00	123.75	126.50	129.25	132.00	134.75
50	137.50	140.25	143.00	145.75	148.50	151.25	154.00	156.75	159.50	162.25
60	165.00	167.55	170.50	173.25	176.00	178.75	181.50	184.25	187.00	189.75
70	192.50	195.25	198.00	200.75	203.50	216.25	209.00	211.75	214.50	217.25
80	220.00	222.75	225.50	228.25	231.00	233.75	236.50	239.25	242.00	244.75
90	247.50	250.25	253.00	255.75	258.50	261.25	264.00	266.75	269.50	272.25
100	275.00	277.75	280.50	283.25	286.00	288.75	291.50	294.25	297.00	299.75
110	302.50	305.25	308.00	310.75	313.50	316.25	319.00	321.75	324.50	327.25
120	330.00	332.75	335.50	338.25	341.00	343.75	346.50	349.25	352.00	354.75
130	357.50	360.25	363.00	365.75	368.50	371.25	374.00	376.75	379.50	382.25
140	385.00	387.75	390.50	393.25	396.00	398.75	401.50	404.25	407.00	409.75
150	412.50	415.25	418.00	420.75	423.50	426.25	429.00	431.75	434.50	437.25

p_c = per cent of consumers who object to the color of the water;

p_t = per cent of consumers who object to the turbidity of the water;

p_o = per cent of consumers who object to the odor of the water;

c = color reading;

t = turbidity reading;

O_v = odors due to vegetable matter, expressed according to standard numerical scale;

O_d = odors due to decomposition, expressed according to standard numerical scale;

TABLE 8.

DEPRECIATION DUE TO TURBIDITY.

Values of D for different values of t in the formula $D=\frac{20\times 5\sqrt{t}}{100}$.

Dollars per million gallons.

Turbidity.	0	1	2	3	4	5	6	7	8	9
0	......	1.00	1.41	1.73	2.00	2.23	2.44	2.64	2.82	3.00
10	3.16	3.31	3.46	3.60	3.74	3.87	4.00	4.12	4.24	4.35
20	4.47	4.58	4.69	4.79	4.89	5.00	5.09	5.19	5.29	5.38
30	5.47	5.56	5.65	5.74	5.83	5.91	6.00	6.08	6.16	6.18
40	6.32	6.40	6.48	6.55	6.63	6.70	6.78	6.85	6.92	7.00
50	7.07	7.14	7.21	7.28	7.34	7.41	7.48	7.54	7.61	7.68
60	7.74	7.81	7.87	7.93	8.00	8.06	8.12	8.18	8.24	8.30
70	8.36	8.42	8.48	8.54	8.60	8.66	8.71	8.77	8.83	8.88
80	8.94	9.00	9.05	9.11	9.16	9.21	9.27	9.34	9.36	9.43
90	9.48	9.53	9.59	9.64	9.69	9.74	9.78	9.84	9.89	9.94

Turbidity.	0	10	20	30	40	50	60	70	80	90
100	10.00	10.48	10.95	11.40	11.83	12.24	12.64	13.03	13.41	13.78
200	14.14	14.49	14.83	15.16	15.49	15.81	16.12	16.43	16.73	17.03
300	17.32	17.60	17.88	18.16	18.43	18.70	18.97	19.23	19.49	19.74
400	20.00	20.24	20.49	20.73	20.97	21.23	21.44	21.67	21.90	22.13
500	22.36	22.58	22.80	23.02	23.23	23.45	23.66	23.87	24.08	24.28
600	24.49	24.69	24.89	25.09	25.29	25.49	25.69	25.88	26.07	26.26
700	26.45	26.64	26.83	27.01	27.20	27.38	27.56	27.74	27.92	28.10
800	28.28	28.44	28.63	28.80	28.98	29.15	29.32	29.49	29.62	29.83
900	30.00	30.16	30.33	30.49	30.69	30.82	30.98	31.14	31.30	31.46
1000	31.62									

O_o = odors due to microscopic organisms, expressed according to standard numerical scale;

H = Hardness of water in parts per million;

d = average temperature of water during four warmest months.

TABLE 9.

DEPRECIATION DUE TO COLOR.

Values of D for different values of c in the formula $D = \frac{20 \times \frac{c}{2}}{100}$.

Dollars per million gallons.

Color	0	1	2	3	4	5	6	7	8	9
0	.....	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9
20	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
30	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
40	4.0	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9
50	5.0	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9
60	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9
70	7.0	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9
80	8.0	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9
90	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9
100	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9
110	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.8	11.9
120	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9
130	13.0	13.1	13.2	3.3	13.4	13.5	13.6	13.7	13.8	13.9
140	14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.7	14.8	14.9
150	15.0	15.1	15.2	15.3	15.4	15.5	15.6	15.7	15.8	15.9
160	16.0	16.1	16.2	16.3	16.4	16.5	16.6	16.7	16.8	16.9
170	17.0	17.1	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.9
180	18.0	18.1	18.2	18.3	18.4	18.5	18.6	18.7	18.8	18.9
190	19.0	19.1	19.2	19.3	19.4	19.5	19.6	19.7	19.8	19.9
200	20.0									

Table 10.

DEPRECIATION DUE TO HARDNESS.

Values of D for different values of H in the formula $D=\frac{H}{10}$.

Dollars per million gallons.

Hardness.	0	1	2	3	4	5	6	7	8	9
0	......	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
10	1.00	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90
20	2.00	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90
30	3.00	3.10	3.20	3.30	3.40	3.50	3.60	3.70	3.80	3.90
40	4.00	4.10	4.20	4.30	4.40	4.50	4.60	4.70	4.80	4.90
50	5 00	5.10	5.20	5.30	5.40	5.50	6.60	6.70	5.80	5.90
60	6.00	6.10	6.20	6.30	6.40	6.50	6.60	6.70	6.80	6.90
70	7.00	7.10	7.20	7.30	7.40	7.50	7.60	7.70	7.80	7.90
80	8.00	8.10	8.20	8.30	8.40	8.50	8.60	8.70	8.80	8.90
90	9.00	9.10	9.20	9.30	9.40	9.50	9.60	9.70	9.80	9.90

Hardness.	0	10	20	30	40	50	60	70	80	90
100	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00
200	20.00	21.00	22.00	23.00	24.00	25.00	26.00	27.00	28.00	29.00
300	30.00	31.00	32.00	33.00	34.00	35.00	36.00	37.00	38.00	39.00
400	40.00	41.00	42.00	43.00	44.00	45.00	46.00	47.00	48.00	49.00
500	50.00	51.00	52.00	53.00	54.00	55.00	56.00	57.00	58.00	59.00
600	60.00	61.00	62.00	63.00	64.00	65.00	66.00	67.00	68.00	69.00
700	70.00	71.00	72.00	73.00	74.00	75.00	76.00	77.00	78.00	79.00
800	80.00	81.00	82.00	83.00	84.00	85.00	86.00	87.00	88.00	89.00
900	90.00	91.00	92.00	93.00	94.00	95.00	96.00	97.00	98.00	99.00
1000	100.00									

TABLE 11.

DEPRECIATION DUE TO ODOR.

Values of D for different values of O_v, O_d, and O_o in the formula

$$D=\frac{20(2O_v^2+3.5O_d^2+5O_o^2}{100}.$$

Dollars per million gallons.

	Odor.	Vegetable odor (O_v).	Odor of decomposition (O_d).	Odor due to organisms (O_o).
0.........	None	0.0	0.0	0.0
1.........	Very faint	0.4	0.7	1.0
2.........	Faint	1.6	2.8	4.0
3.........	Distinct	3.6	6.3	9.0
4.........	Decided	6.4	11.2	16.0
5.........	Strong	10.0	17.5	25.0

TABLE 12.

DEPRECIATION DUE TO TEMPERATURE.

Values of D for different values of d in the equation $D=\frac{(d-45)^2}{180}$.

Dollars per million gallons.

Temperature.	0	1	2	3	4	5	6	7	8	9
40	.....	.....	.....	.....	.....	.....	.....	0.02	0.01	0.09
50	0.13	0.20	0.27	0.35	0.45	0.56	0.68	0.80	0.94	1.09
60	0.25	1.25	1.61	1.80	2.01	2.22	2.45	2.69	2.94	3.20
70	3.45	3.75	4.05	4.35	4.68	5.00	5.34	5.69	6.05	6.43
80	6.81	7.20	7.60	8.03	8.45	8.90	9.35	9.80	10.28	10.75

Application of the Formulæ

It now remains to apply the principles above set forth to actual cases and see to what conclusions they lead.

EFFECT OF CONTAMINATION

The average death-rate from typhoid fever in American cities which have more than 30,000 inhabitants is about 35 per 100,000. Applying formula (1), and assuming a value of 20 for N, then

$$D = 2.75(35 - 20) = \$41.25;$$

that is, the average depreciation of the water-supplies of our American cities, taken as a whole, is \$41.25 per million gallons, because of their unsanitary quality, or about \$15,000 per annum for each million gallons a day of supply.

The above figure takes into account both good and bad supplies. The average typhoid-fever death-rate in those cities which have reasonably good water-supplies may be taken in round numbers as about 20, while in those cities which have supplies more or less contaminated it varies from this up to 40 or 60. In some of the worst cases it is more than 100 per 100,000. In Pittsburg, for example, the typhoid death-rate for several years has averaged 120. Here, according to formula (1), $D = 2.75(120 - 20) = \$275$ per million gallons. This is figured, however, on a per-capita water consumption of 100 gallons a day. The actual consumption is about 250 gallons per capita per day; hence D should be taken as $\frac{100}{250}$ of \$275, or \$110 per million gallons.

Each million gallons of polluted Allegheny River water pumped to Pittsburg has therefore reduced the vital assets of the community by \$110. This, for a population of 350,000, amounts to \$3,850,000 per year—a sum enormously greater than the annual cost of making the water pure.

Classifying water-supplies according to their source, the following will give a general idea as to the depreciation of various types of water from the sanitary standpoint, based on general average typhoid-fever death-rates:

CHARACTER OF WATER-SUPPLY.

	Depreciation in dollars per million gallons.
1. *Ground-waters*, except in cases where pollution is excessive, or where wells are driven in rock or soil abounding in fissures	\$0.00
2. *Filtered waters* (assuming modern methods of construction and operation)	0.00
3. *Surface-waters:*	
(*a*) Ordinary upland waters, with insignificant contamination	\$0.00 to \$15.00
(*b*) Slightly contaminated waters, with good storage in lakes or large reservoirs	10.00 to 50.00
(*c*) River-waters, slightly contaminated, little or no storage	25.00 to 100.00
(*d*) River-waters, much contaminated, little or no storage	50.00 to 200.00

EFFECT OF TURBIDITY, COLOR, AND ODOR

It has been shown that the æsthetic deficiency of water depends upon three variable characteristics, which may have many different combinations; conse-

TABLE 13.

EXAMPLES OF WATERS WITH DIFFERENT PHYSICAL CHARACTERISTICS.

City.	Source of supply.	Turbidity.	Color.	Odor.	Per cent of objecting consumers.	Depreciation per million gallons.
	GROUND-WATERS.					
Camden, N. J....	Driven wells.........	0	1	0	0	0.00
Flatbush, L. I...	Driven wells.........	0	0	0	0	0.00
Lowell, Mass. ...	Driven wells.........	0	10	0	5	1.00
	SURFACE-WATERS.					
Portland, Me. ...	Lake Sebago	1	15	2*v*	20	$4.00
Boston, Mass. ...	Sudbury and Nashua rivers............	3	25	2*v*	30	6.00
Cleveland, Ohio .	Lake Erie...........	18	5	1.5*v*	30	6.00
Worcester, Mass.	Storage reservoirs....	2	30	3*v*	40	8.00
New York City. .	Croton River........	4	20	3*v*	55	11.00
Brooklyn, N. Y..	Ponds and driven wells on Long Island.....	3	13	1.5*g*	36	7.20
Jersey City, N. J.	Rockaway River.....	4	32	2*v*.1*g*	38	7.60
Watertown, N.Y.	Black River.........	6	70	3*v*	55	11.00
Springfield, Mass.	Ludlow reservoir.....	5	27	4*g*	104	20.80
Bangor, Me.	Penobscot River.....	6	65	3*v*.1*m*	59	11.80
Pittsburg, Pa. ..	Allegheny River.....	64	30	3*v*.2*m*	87	17.40
Philadelphia, Pa.	Schuylkill River.....	150	10	3*v*.2*m*	102	20.40
St. Louis, Mo. ...	Mississippi River.....	200	30	3*v*.2*m*	127	25.40

Some of the above figures do not represent present conditions. For example, Watertown, N. Y., now has filtered water; St. Louis uses a chemically treated water; etc.

quently it is difficult to classify the water-supplies of the country on this basis. For this reason the few typical examples given in Table 13 may be more instructive than any attempt at a general classification.

It will be seen from the above figures that, while the

general attractiveness of a water is of less importance than its sanitary quality, yet it is by no means insignificant. For instance, such a water as that now supplied to New York City from the Croton River has a depreciation of $11 per million gallons, or nearly a million and a half dollars a year for a daily supply of 350 million gallons. At 4 per cent this represents the interest on about $35,000,000, a sum several times as large as the cost of filtration. An algæ-laden water like that of Ludlow Reservoir at Springfield, Mass., has a depreciation of more than $20 per million gallons, because of its odor and turbidity. A colored water like that of the Black River at Watertown before filtration has a depreciation of $11, while a turbid water like that of the Mississippi River at St. Louis gives $25.

In most surface-waters the physical characteristics vary greatly at different times of the year. During the spring and fall, for instance, the color and turbidities may be high on account of rains, while during the summer the water may have bad odors due to microscopic organisms. The following depreciations of certain reservoir waters, calculated as above described, serves well to show this seasonal variation.

TABLE 14.

ORDINARY SEASONAL VARIATION IN THE DEPRECIATION OF A SURFACE-WATER DUE TO CHANGES IN TURBIDITY, COLOR, AND ODOR.

Month.	Turbidity.	Color.	Odor.	Per cent objecting consumers.	Depreciation per million gallons.
January.....	6	25	3*v*	44	\$8.80
February....	8	28	3*v*	47	9.40
March........	7	27	3*v*	45	9.00
April.........	5	22	3*v*+	40	8.00
May........	8	25	(3*v*.0.5*g* 0.3*m*)	49	9.80
June........	7	30	(3*v*.0.3*m*)	48	9.60
July........	4	22	(3*v*.0.5*g* 0.5*m*)	43	8.60
August......	4	25	(3*v*.2. *g* 0.5*m*)	62	12.40
September...	3	30	(3*v*.1. *g* 0.5*m*)	63	12.60
October.....	4	28	(3*v*.1. *g* 0.5*m*)	49	9.80
November...	3	26	(3*v*.0.3*m*)	40	8.00
December...	4	25	(3*v*.0.3*m*)	42	8.40
Average...	......	......	....	....	\$9.53

TABLE 15.

EXTREME CASE OF SEASONAL VARIATION IN THE DEPRECIATION OF A SURFACE-WATER DUE CHIEFLY TO GROWTHS OF ALGÆ.

Month.	Turbidity.	Color.	Odor.	Per cent of objecting consumers.	Depreciation per million gallons.
January..........	1	25	2*v*	26	\$5.20
February.........	1	42	2*v*	34	6.80
March............	2	40	2*v*	35	7.00
April............	2	41	2*v*	36	7.20
May............	5	38	3*v*	48	9.60
June............	10	43	2*g*	58	11.60
July............	15	45	3*g*	87	17.40
August...........	25	64	4*g*	137	27.40
September........	25	57	4*g*	133	26.60
October..........	15	28	3*g*	78	15.60
November........	5	24	3*v*	41	8.20
December........	3	26	2*v*	30	6.00
Average.......	....	....	....	....	\$12.38

EFFECT OF HARDNESS

The waters of New England are comparatively soft, although in some instances the ground-waters are hard. In the Middle West, on the contrary, most of the surface-waters are quite hard, and in some cases the hardness is excessive. The following figures serve to give an idea of the range in the depreciation of waters due to hardness.

TABLE 16.

State.	City or town.	Source of supply.	Total hardness (parts per million).	Depreciation per million gallons.
Maine	Augusta	Kennebec River	20	$2.00
"	Waterville	Messalonskee River	15	1.50
Massachusetts	Boston	Sudbury and Nashua rivers	12	1.20
"	Cambridge	Storage reservoir	33	3.30
"	Pittsfield	Storage reservoir	50	5.00
New York	New York	Croton River	40	4.00
"	Albany	Hudson River	64	6.40
"	Oswego	Oswego River	191	19.10
Pennsylvania	Philadelphia	Schuylkill River	179	17.90
Ohio	Toledo	Maumee River	200	20.00
"	Columbus	Scioto River	335	33.50
"	Warren	Mahoning River	578	33.50
England	London	Chelsea Company	215	21.52
"	London	East London Company	243	24.30

Benefits of Filtration

The filtration of a water improves its quality in many ways. It not only makes the water wholesome, but it

improves its general attractiveness. By using a properly designed filter-plant, supplemented if necessary by sedimentation or aëration or chemical treatment according to local needs, an infected water may be made safe to drink, a turbid water may be clarified, a colored water rendered colorless, a bad-smelling water made savory, and a hard water made soft. By the application of the formulæ above described the beneficial effects of filtration may be clearly demonstrated.

Sanitary quality.—The following figures show to what extent the sanitary value of a polluted public water-supply is increased by an efficient system of filtration:

Lawrence, Mass.:

Water-supply, Merrimack River, filtered by a slow sand-filter.
Population, 70,000.
Water consumption, 40 gallons per capita daily.
Before filtration the typhoid-fever death-rate was 121 per 100,000; since then it has been 26.
Before filtration $D=2.75(121-20)\times\frac{100}{40}=\$693$.
After filtration $D=2.75(26-20)\times\frac{100}{40}=\$41$.
Increase in sanitary value $=\$693-\$41=\$652$ per million gallons, or \$665,000 per year, or \$9.50 per year per capita.

Albany, N. Y.:

Water-supply, Hudson River, filtered by sand-filter.
Population, 95,000.
Water consumption, 165 gallons per capita daily.
Before filtration the typhoid-fever death-rate was 104 per 100,000; since then it has been 26.
Before filtration $D=2.75(104-20)\times\frac{100}{165}=\$140$.

Albany, N. Y. (Continued):

After filtration $D=2.75(26-20)\times\frac{100}{165}=\$10$.

Increase in sanitary value $=\$140-\$10=\$130$ per million gallons, or \$450,000 per year, or \$4.75 per capita per year.

Binghamton, N. Y.:

Water-supply, Susquehanna River, filtered by a mechanical filter.

Population, 42,000 (approximately).

Water consumption, 160 gallons per capita daily.

Typhoid-fever death-rate before filtration, 49; after filtration, 11 per 100,000.

Before filtration $D=2.75(49-11)\times\frac{100}{160}=\$65$.

After filtration $D=2.75(11-11)\times\frac{100}{160}=0$.

Increase in sanitary value $=\$65.00$ per million gallons, or \$160,000 per year, or \$3.80 per capita per year.

Watertown, N. Y.:

Water-supply, Black River, filtered by mechanical filter.

Population, 25,500 (approximately).

Water consumption, 160 gallons per capita daily.

Typhoid-fever death-rate before filtration, 97 per 100,000; after filtration, 27.

Before filtration $D=2.75(97-20)\times\frac{100}{160}=\$132.34$.

After filtration $D=2.75(27-20)\times\frac{100}{160}=12.0$.

Increase in sanitary value $=\$120.34$ per million gallons, or \$175,000 per year, or \$6.90 per capita per year.

Illustrations like the above might be multiplied, but the four cases selected are sufficient to illustrate the general fact. It is easily seen from them that the filtration of a polluted public water-supply increases to a very great extent the vital assets of a community, and the increase in most cases is many times greater than the cost of constructing and operating the works.

Money paid to the doctor, the apothecary, and the undertaker is not, in one sense, a loss to a community, as it is merely a transference of money from one man's pocket to another's, but in the broader sense any loss of productive capacity or any unnecessary expenditure is a loss. Deaths from typhoid fever and from other diseases, however, represent a very material loss of the productive capacity of a community, and consequently a decrease in what may be termed the "vital assets." In the case of the city of Albany, for instance, the increased worth of the water to the city, because of its efficient filtration, amounts to \$475,000 per year, of which at least \$350,000 may be considered as a real increase in the vital assets of the city.

If in the formula $D = \$2.75(T - N)$ we let $T - N = 1$, then $D = \$2.75$; that is, a decrease in the typhoid-fever death-rate of 1 per 100,000 causes an increase in the vital assets of the city of \$2.75 for each million gallons of the public water-supply (assuming this to be 100 gallons per capita), or \$0.10 per capita per year for each unit reduction of the typhoid-fever death-rate per 100,000. In other words, the decrease in the typhoid death-rate per 100,000 divided by 10 gives the increased vital assets of the community in dollars per capita per year. Thus, in the case of Albany, above given, the reduction in the typhoid-fever death-rate was 78 per

100,000. On the basis of 10 cents per capita per unit decrease, this would amount to $\$0.10 \times 78 \times 95{,}000 =$ \$741,000 per year, assuming a per-capita consumption of 100 gallons daily, or \$450,000 for a per-capita consumption of 165 gallons daily, which is the figure stated above.

Looking at the matter in another way, it may be said that the purification of a polluted water is a sort of life-insurance for the people, the value of which is equal to 10 cents per capita for each unit decrease in the typhoid-fever death-rate per 100,000 which it brings about. Such a sum capitalized represents a large amount of money. In Albany, for example, where the typhoid-fever death-rate has been reduced 78 per 100,000, the annual saving of life-value would be \$7.80 per capita. Capitalized on the basis of an annual life-insurance premium of \$17 per thousand, this would represent an insurance policy of about \$460 per year for each inhabitant, or \$2,300 for each head of a family.

Physical quality.—The figures of Table 17 show the effect of filtration on the attractiveness of waters—that is, upon the aggregate effect of their physical characteristics.

These figures do not pretend adequately to represent the conditions in any of the cities included in the list, as the analysis in each case represents only one

TABLE 17.

City.	Source of supply.	Type of filter.	Sample.	Turbidity.	Color.	Odor.	Per cent of objecting consumers.	Depreciation. Per million gallons.	Increased value of water. Per million gallons.
Lawrence, Mass. . .	Merrimack River	Slow sand	Raw	10	40	3v 1m	58	$11.60	
			Filtered	0	40	2v	28	5.60	$6.00
Albany, N. Y.	Hudson River	Slow sand	Raw	40	32	3v 1m	69	13.80	
			Filtered	2	24	2v	27	5.40	8.40
Yonkers, N. Y.	Sawmill Creek	Slow sand	Raw	6	30	1v 1m	49	9.80	
			Filtered	0	3	1v	4	0.80	9.00
Poughkeepsie, N.Y.	Hudson River	Slow sand	Raw	30	55	3v 1m	78	17.60	
			Filtered	0	30	1v	17	3.40	14.20
Binghamton, N. Y.	Susquehanna River	Mechanical filter	Raw	30	20	3v	57	11.40	
			Filtered	0	5	1v	5	1.00	10.40
Watertown, N. Y.	Black River	Mechanical filter	Raw	6	70	3v	72	14.40	
			Filtered	0	8	1v	10	2.00	12.40
Little Falls, N. Y.	Passaic River	Mechanical filter	Raw	20	35	3v	56	11.20	
			Filtered	0	8	1v	10	2.00	9.20
Brooklyn, N. Y. . . .	Baisley's Pond	Mechanical filter	Raw	15	31	2v	52	10.40	
			Filtered	2	3	0	7	1.40	9.00

date. They are, however, typical of what the filters in the various places are doing, and they indicate that the increased value of the water, because of its filtration, is as great as the cost of the works—in some cases it is even greater. Thus if the effect of filtration on the sanitary qualities of these waters is entirely ignored, and only its effect on their physical qualities considered, the filtration of these supplies would still be a profitable undertaking from a financial standpoint. If the sanitary qualities were also considered, the advantages of filtration would be found to be many times greater.

Water-softening.—The following figures will illustrate the financial value of water-softening plants:

Winnipeg, Manitoba:	
Hardness of water before treatment	580
Hardness of water after chemical treatment and filtration	193
Reduction in hardness	387
Increased value of water due to water-softening process, per million gallons	$38.70
Oberlin, Ohio:	
Hardness of raw water	170
Hardness of raw water after chemical treatment and filtration	48
Reduction in hardness	122
Increased value of water due to water-softening per million gallons	$12.20

These figures refer only to water used for domestic

purposes. If industrial uses also were considered, the advantages of water softening would be still more evident.

At the present time there are not many water-softening plants in existence in connection with municipal supplies, but the advantages to be gained are very great, and are becoming appreciated by the managers of railroads and industrial establishments. With a better understanding of the practical benefits to be derived from the use of soft water, it may be confidently expected that during the next ten years the number of municipal water-softening plants will very greatly increase.

Cost of Filtration

In order that the reader may have some basis with which to compare the cost of filtration with the benefits derived the following paragraph is quoted from a paper by Allen Hazen on "Purification of Water for Domestic Use," read at the International Engineering Congress in St. Louis in 1904. (Transactions Am. Soc. C. E., Vol. LIV, Part D, 1905.)

"During the decade there has been a wonderful advance in the design and management of purification plants. The effect of these changes has had two effects

upon the cost. On the one hand, more exacting requirements have constantly led to the use of better and more adequate appliances and to more thorough systems of operation, and this has tended to increase the cost. On the other hand, improvements in design and the development of mechanical appliances to perform parts of the work formerly accomplished by hand labor have tended to reduce the cost. On the whole, it is, perhaps, fair to state that the improved methods and the increased efficiency have been secured without any material change in the cost of the process, although, of course, there are many exceptions, some in one direction and some in the other.

"As a general average, with a well-designed modern plant adapted to its work, the cost of filtering water, exclusive of pumping, but including all costs of operating the filters and furnishing the supplies required, and including the interest on the cost of the works and a reasonable allowance for repairs and depreciation, will amount to about $10 per million gallons, or one cent per thousand gallons of filtered water. Occasionally, with very easily treated water, and with conditions favorable for cheap construction, the cost may be as low as $6 or $8 per million gallons. On the other hand, with waters which are difficult to treat, or where the conditions of construction are difficult, the cost may be

increased to $15 or even $20 per million gallons. In a general way, the purification of the water adds from 10 to 20% to the entire cost of furnishing and supplying water to an American city. The percentage is usually less as the works for securing the water are more extensive. Where water is carried long distances (the absolute cost of purification remaining the same) the percentage is much less than where water is obtained from sources in the immediate vicinity. This cost of filtration, although a small percentage of the whole cost of water-works, has been large enough to prove a substantial obstacle to the adoption of filters in many cases."

Summary

In the foregoing study attention has been called to the following propositions:

1. Pure water as compared with impure water has a real financial value to a community.

2. This value may be measured by determining what impure water costs the community.

3. There are three principal characteristics which affect the value of water to the general consumer—its sanitary quality, its general attractiveness, and its hardness.

4. A formula is suggested for computing the effect of

the sanitary quality of water on its financial value to a community. It is based on the typhoid-fever death-rate.

5. A formula is suggested for computing the effect of the general attractiveness of water on its value to consumers. It is based on the physical characteristics of turbidity, color, and odor.

6. A formula is suggested for computing the effect of the hardness of water on its value to the consumers. It it based on the use of soap in the household.

7. Considered from the financial aspect alone, and disregarding all humanitarian considerations, the filtration of a polluted water-supply adds very greatly to the vital assets of a community; hence, as a mere business proposition, no city can afford to allow an impure water-supply to be publicly distributed.

8. The advantages to a community of having a water-supply, not only safe but also attractive in appearance, taste, and odor, are material from a financial aspect. The increased value of many waters because of the improvement in their æsthetic qualities alone justifies the cost of filtration.

9. Water-softening at present does not receive the attention it deserves at the hands of municipal authorities. The economic advantages to be gained by removing the hardness of water are so great that, in

many cases, the saving to the ordinary water-consumer justifies the cost of softening water.

10. The formulæ here suggested and the detailed results derived from their use are not to be considered as of great accuracy, as the assumed data are not fully adequate. They are given merely to show the possibility of computing the value of pure water in terms of dollars and cents, and to illustrate the financial value of filtration and justify its cost.

WHAT IS "PURE AND WHOLESOME WATER"?

(Extract from an address delivered at Albany, October 5, 1905, at a Conference of the Sanitary Officers of New York State on "The Pollution of Streams and the Natural Agencies of Purification.")

IT is always difficult to adhere to strict definitions when popular words are used in a scientific sense. The very simplicity of the expression "pure water" makes it hard to define—especially so to a chemist who knows that no natural waters are absolutely pure and that at best he can apply the term only in a relative sense.

In the first place, it must be recognized that river-waters in a state of nature vary greatly in purity; some are clear, colorless, and sparkling, some are muddy and high-colored, some are saline, some are chalybeate, some are sulphurous. Of these various waters part are wholesome, part are not; and their wholesomeness does not depend upon the characteristics just mentioned. In the second place, river-waters may receive additions of artificial substances of several classes—those which

do not injure its quality in any material or noticeable way, such as common salt or lime; those which injure its appearance or odor or impregnate it with objectionable chemical constituents, but which do not tend to make the water disease-producing, such as dyestuffs; those which tend to render the water poisonous, as the salts of lead or tin; and those which tend to make the water capable of producing infectious diseases, such as sewage. Of course substances of any of these classes added to the water in excessive amounts injure its quality for some uses. In the third place, we must recognize in practice as well as in theory that when water produces diseases it does so chiefly by transmitting living organisms or their spores from one human being, or possibly from some animal, to another human being or animal. In the fourth place, it must be remembered that in public water-supplies the quality of the water must be considered for industrial uses as well as for drinking. And lastly, the fact must not be overlooked that not all river-waters are used for public water-supplies and that it is not necessary to maintain in such the same degree of purity as when they are to be used for drinking. In this case the standard is not a hygienic one, but an æsthetic one.

Our ordinary vocabulary applies to objectionable waters such words as *contaminated*, *polluted*, *infected*,

befouled, defiled, tainted, corrupted, stained, impure, soiled, putrid, etc., while to describe good and generally satisfactory waters we have only the positive words *pure, safe,* and *wholesome.* With so many words in use, either our language is redundant or we are using words carelessly and without regard to their exact meaning. In the following arrangement of definitions I run the risk of contradicting some authorities, but I believe it to be representative of the best current usage and, at any rate, to make for clearness of expression.

Epithets Especially Applicable to Waters in a Natural State

A *stained water* is one which is colored by vegetable extractives from leaves, soil, etc. (The term "colored water" is a better one.)

A *soiled water* is one made dirty by washings from the soil, that is, by clay, silt, etc. (The term "turbid" is a better one.)

A *tainted water* is one which has an unpleasant odor, due to the decomposition of organic matter, to the presence of algæ, etc.

A *putrid water* is one in which the decomposition of organic matter has reached such a degree that all the dissolved oxygen has disappeared and the water

become offensive to sight or smell. (This term is more often applied to polluted waters.)

An *impregnated water* is one which contains chemically dissolved such substances as lime, magnesia, soda, salt, iron, hydrogen sulphide, etc., in quantities sufficient to be objectionable for the purpose for which the water is to be used. (In small quantities the presence of these substances might pass without comment.)

Epithets Applicable to Water with Artificial Substances Admixed

A *polluted water* is one which has received and still holds the excreta of human beings or animals, or the waste product of human industry. The word "pollution" may be used as a general term to cover all substances artificially admixed with water. Polluting matter may be divided into that which contaminates and that which merely tends to make the water foul.

A *befouled water* or a defiled water is one which has received and holds matter tending to make it foul, unsightly, or ill-smelling, but which is not of excrementitious origin.

A *contaminated water* is one which has received and holds excrementitious matter, whether from human beings or animals. Such a water does not necessarily

contain disease germs, though this must be always considered as possible. (The word "contamination" is often used as a synonym for pollution and given a more general application, but its restricted meaning seems to serve a more useful purpose.)

An *infected water* is one which actually contains pathogenic bacteria capable of producing disease. Such disease germs are nearly always of excrementitious origin.

A *poisoned water* is one which contains some poisonous chemical substance. (This occurs rarely, except in the case of lead.)

It will be seen that river-waters may be stained, or soiled, or tainted, and even putrid, and yet not be polluted, while polluted waters need not necessarily be visibly stained or soiled or tainted.

A water may be polluted and yet not be contaminated with sewage or contain disease germs; a water may be contaminated even and yet not actually contain disease germs (this statement is only tentatively advanced); but a contaminated water is necessarily a polluted water, while an infected water is both polluted and contaminated. A sharp distinction must be made between befouled waters and contaminated waters, as these terms distinctly separate sewage from trade wastes.

Now, what are pure and safe and wholesome waters?

The last two have nearly equivalent meanings. *safe water* may be taken as one which is neither poisonous nor infected nor contaminated, that is, one which is not liable to cause actual disease.

A *wholesome water* is a safe water and one which is not befouled, stained, soiled, or tainted enough to injure the health or to make the water too unattractive to use. Preferably also it should be well aerated.

A *pure water* implies much more; it must not only be not poisonous, not infected, not contaminated, and not appreciably befouled, but besides this it must be practically unstained, unsoiled, and untainted, as well as unimpregnated with noticeable amounts of objectionable chemical salts. Obviously there may be different degrees of purity, but absence of contamination and practical absence of befoulment must be considered in any case as a *sine qua non.*

Now that we have defined these terms from a sanitarian's point of view let us see how the analyst defines them and what tests can be applied to differentiate them. We cannot go into this subject minutely without consuming too much time, but it should be noted that the tests which make up the water analysis may be divided into four groups—physical, chemical, microscopical, and bacteriological—which serve different purposes.

Waters naturally stained, soiled, or tainted may be studied by physical tests alone, which can be made out of doors with very simple apparatus, though in studying tainted waters a microscopical examination of the algæ, etc., is of great value.

Befouled waters must be studied chemically as well as physically and microscopically. The amount of organic matter, nitrogenous and carbonaceous, must be determined as well as some of the mineral constituents. Sometimes, and especially when the befoulment is large, the dissolved gases, oxygen and carbonic acid, must be determined to see if there is danger of putridity. Bacteriological examinations are also sometimes helpful.

Bacteriological examinations are especially necessary, however, in the study of contamination. Here they are absolutely essential, and the tests must be such as to reveal not only the number of ordinary water-bacteria but those which are commonly associated with fecal matter and sewage. Among these the test for the colon bacillus is of most value, as the presence of this organism and its relative abundance is the best index of contamination that we have. It is desirable, however, and often necessary to have chemical, physical, and microscopical examinations accompany the bacteriological tests. Indeed, these four tests are now generally recognized as constituting a modern sanitary water-analysis,

and their testimony should be interlocking, one part helping to explain the other.

Beyond proving a water to be contaminated we cannot go at present with our laboratory methods. We cannot tell by analysis with certainty that a water is or is not actually infected with disease germs. I do not mean that it is absolutely impossible to say that a water contains, for instance, the germs of typhoid fever—for typhoid-fever germs may be and have been isolated from water samples—but our tests are not so reliable that if we obtained a negative result we could say that the water was not infected. We hope the time will come when we may do this, but we cannot do it now.

At present, therefore, in order to be on the safe side, we must consider contamination as potential infection, inasmuch as infection originates in contamination, and we must deal with a contaminated water as though it were infected.

The interpretation of a water-analysis is a difficult matter and one which requires a wide experience with different classes of natural and polluted waters. To distinguish between contamination and befoulment is often a difficult matter even for the expert. In all cases a knowledge of the natural or normal quality of the water must be known, or at least mentally esti-

mated, before the results of the analysis can be properly interpreted. It is for this reason that a knowledge of the source of the water is necessary to the analyst and that modern sanitary science lays so much stress upon the importance of sanitary inspection.

For an ordinary man to draw a conclusion from the figures of a chemical analysis is like trying to determine the state of business by studying the stock quotations as they appear for a few moments on the ticker. If he has a mental picture of all that has happened on the market for many weeks, the quotations may mean something to him, but otherwise they do not.

THE DISADVANTAGES OF HARD WATER

(From a lecture delivered at the Brooklyn Polytechnic Institute, January 9, 1906.)

HARD waters have always been considered objectionable for common use. Universal experience is summed up in the apologetic qualification heard so often, "We have good water here, *but it is hard*." In recent years the economic importance of hard waters has been lost sight of to a considerable extent, in view of the greater prominence of sanitary matters. Engineers and manufacturers are now studying the subject anew, and the more it is studied the more its importance becomes apparent. It is seen that in some industries the difference between a hard water and a soft water may mean the difference between loss and profit on the balance sheet; in others it may mean a change of the location of a factory. It may mean a difference in the quality of the manufactured product, or the success or failure of some chemical process. It may mean changes in labor, in rates of transportation, in railroad time-table sched-

ules: it may mean accidents, attended with loss of property and even of human lives.

The term "hard water" should be strictly applied to waters which contain salts of calcium and magnesium, particularly their carbonates and sulphates, but in popular and local parlance it is frequently, though erroneously, applied to waters which contain other substances, such as iron, sodium chloride, and even free acids or alkalies. In studying the subject in its general aspect it seems best to include these other mineral constituents which have a bearing on the problem.

Use of Hard Water in the Household

Hard water is unsatisfactory for household use for several reasons. The money loss due to the waste of soap has been already considered, but the inconveniences of its use are perhaps more important than the money loss involved. In using hard waters for washing the hands and for bathing, the calcium and magnesium stearates are precipitated by the soap and give rise to unsightly scums in the wash-bowl and bath-tub. They tend to fill the pores of the skin, preventing a thorough cleansing and causing the hands to chap. They also prevent the formation of a good lather in shaving.

It is in the laundry that the effects of hard water

are most noticeable. Not only are large amounts of soap required to produce a lather, but the stearates above mentioned settle on the clothes, fill the pores, and tend to rot them and make them look dingy. Hard waters also encourage the use of strong soaps, washing compounds, etc., which may contain ingredients destructive of the fabrics.

In culinary operations, such as in making tea, hard waters are less satisfactory than soft waters, as they increase the color but decrease the aroma. This is a fact which few housekeepers do not fully realize, but which may be easily demonstrated by experiment. Every one knows that hard waters cause a crust to form on the walls of the tea-kettle. The same incrustation forms on the interior of the "water back" of the kitchen stove and interferes with the proper operation of water heating.

The physiological effects of ordinary hard water, so far as known, are insignificant, and most of the theories which have been advanced to show the great danger of drinking distilled water, or, on the other hand, the evil effects produced by drinking-water containing salts of lime, are without substantial foundation. Waters of excessive hardness, or those which contain considerable amounts of sodium sulphate, alkalies, magnesium salts, etc., may, however, produce decided

physiological disturbances. It is said that persons of a rheumatic tendency often find partial relief by changing from a hard to a soft water.

The taste of hard water is largely a matter of personal idiosyncrasy or habit. Some persons prefer hard water, while others like soft water. As a rule, water does not taste hard unless the hardness exceeds 50 parts per million. Much depends upon the nature of the mineral salts present and a good deal upon the sensitiveness of the individual.

Some tastes are particularly sensitive to chlorides, others to alkalies, others to such astringents as alum or ferrous sulphate. The following results of some experiments on taste sensitiveness, made by Mr. Melville C. Whipple, are interesting in this connection. Solutions of different strengths of some of the more common salts found in drinking-water were submitted to about twenty individuals for the purpose of ascertaining the smallest amounts which could be detected by the taste. The figures in the table indicate the number of observers who could detect a taste in distilled water containing the various salts to the amounts indicated, though they do not necessarily mean that the particular taste could be recognized in that dilution. It is interesting to notice that in the case of well-known tastes, such as those of sodium chloride

TABLE 18.

TABLE SHOWING THE NUMBER OF OBSERVERS WHO COULD DETECT BY TASTE THE PRESENCE OF VARIOUS SALTS DISSOLVED IN DISTILLED WATER IN AMOUNTS EQUAL TO OR LARGER THAN THOSE INDICATED.

Parts per Million.

Salts	0.5	1	5	10	15	25	50	75	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900
Potassium chloride	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	...	2	1	3						
Potassium hydroxide	...	2	...	4	...	2	1																		
Sodium carbonate	...	...	...	...	4	7	...	2																	
Sodium chloride	...	...	...	...	...	...	...	...	...	...	2	1	7	3	2	2									
Sodium hydroxide	...	1	1	3	2	1	1																		
Sodium nitrate	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	1	3	2	...	2	...	2	2	
Sodium sulphate	...	...	...	...	...	...	...	...	...	...	...	1	3	4	3	2	...	1							
Calcium carbonate	...	...	...	...	...	...	5	2	3	2	1														
Calcium chloride	...	...	...	...	...	...	...	...	...	5	2	7	1	2											
Calcium oxide (CaO)	...	...	2	3	2	1	1																		
Calcium sulphate	...	...	...	...	...	...	...	...	...	...	...	2	1	1	1	1	2	1	2	1	...	...	2	1	1
Magnesium carbonate	...	...	...	...	...	2	1	3	4	...	...	2	1												
Magnesium chloride	...	...	...	...	...	...	...	...	...	...	4	1	2	1	...	1	1	1	2	1	1	4			
Magnesium nitrate	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1	5	3	2	3	1	1		
Magnesium sulphate	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	2	3	4	3						
Ferrous sulphate	2	5	13	2																					
Aluminum sulphate	...	...	...	...	...	6	1	5	8	2	1														
Copper sulphate	...	...	2	2	5	3																			
Sea-water *	...	...	...	...	...	...	...	...	...	3	4	3	2	3	...	2	...	...	6						

* In terms of parts per million of chlorine.

and sodium carbonate, there was considerable unanimity among the observers, while in the case of tastes not so well known the differences in the various limits of taste were wide.

Chlorinated waters are often the source of much annoyance and expense to the householder on account of their tendency to cause corrosion of the plumbing. The copper-lined flush tanks with soldered seams, so commonly used, soon become corroded and have to be replaced in cities where the amount of chlorine in the water is large. This is due to galvanic action set up between the copper and the solder. This corrosion is more likely to occur in clear waters than in those which are so turbid that they form deposits in the tanks and so protect the metals from the galvanic action. Instances are on record where the filtration of water has increased the number of tank corrosions by making the water clearer, thus facilitating the galvanic action.

Iron-bearing waters are often very annoying to the householder. By precipitation of iron oxide they may render the water turbid, make stains of iron-rust on clothes, choke up the pipes, tanks, etc., and form brown stains in marble wash-bowls under the faucets.

Use of Hard Water in the Industries

In almost every instance where chemical manufacturing processes involve the use of water its hardness affects the result. The effect may be an economic one and cause merely a waste of material, but it may be a vital one and influence the entire process. As illustrations, the operations of bleaching and dyeing, tanning, sugar-refining, and paper-making may be mentioned.

Dyeing is a process which involves many very delicate reactions and in which immense quantities of water are used in mixing the colors and in washing the goods. In dyeing silk, for instance, 1,000 gallons of water are sometimes used for each pound of silk. Many aniline colors dissolve badly in calcareous waters. The colors of cochineal, methyl blue, etc., are materially altered by the presence of hardening constituents, and, as hard waters often fluctuate in hardness, the matching of delicate colors is a matter of difficulty. In madder-dyeing hard waters may not only cause changes of shade, but may cause precipitates to form in spots on the goods. In wool-dyeing the effect of hard waters is noticeable. The fibres do not become well degreased, and insoluble calcareous soaps deposit on the threads, so that they do not take the dye evenly. Ferruginous

waters are, of course, highly objectionable, especially in white dyeing or bleaching.

Great quantities of water are used in tanning. The unhairing of the skin is done by loosening the roots of the hair by saponifying with quicklime the greasy matter secreted by the small hair-glands. If the water contains a large amount of calcium carbonate, some of this is precipitated on the dermal tissue. This deposit interferes with the absorption of the tannin in the cells of the hide and causes brown stains to appear on the leather.

Sugar-refining requires pure water. It is used in filtering the syrups through animal charcoal. This charcoal has the power of absorbing the hardening constituents of water, and if it does this to a considerable extent it quickly loses its bleaching power, which has to be restored by treatment with dilute hydrochloric acid. In manufacturing beet-root sugar the phenomenon of osmosis comes into play between the water and the juice of the beet-root, the cell-walls playing the part of a dialyzer. Hard waters are harmful in this operation, as they tend to cause an appreciable amount of sugar to be retained in the mother-liquor. The lower the salts in solution the easier it is to eliminate the saline matter from the molasses and increase the yield of sugar.

Hard water is unsuited for paper-making for several reasons. It interferes with the sizing used on the paper and has an important effect on dyeing, as mentioned above. Iron salts especially are objectionable in a paper-mill. Under the influence of an alkali the iron is precipitated on the paper, giving rise to brown spots and streaks. Hardness affects the process of paper-making in another way. The paper-pulp is carried over two sheets of wire gauze, and if lime is present in the water the pores of the wire gauze are likely to become choked up with what is called "water stone," which is really nothing else than calcium carbonate.

Many other industries might be mentioned in which hard waters play an important part, such, for instance, as the manufacture of soap, wool-scouring, printing, brewing and distilling, photography, ice-making, etc. It would be interesting if some industrial chemist would take up this matter and furnish the data now lacking, to show, in dollars and cents, the effect which hard water has on these various manufacturing processes.

Use of Hard Water in Steam-making

Steam users suffer more from the bad effects of hard waters than any one else, consequently the use of hard water in boilers requires more than a passing notice.

The economical operation of a boiler demands good water as much as it does good coal. This is better appreciated to-day than it was a few years ago. With the older boilers of small size and simple type, the character of the water was of less importance, but the present-day striving for economy in steam production, which has resulted in the use of so many auxiliary attachments to the modern boiler, requires that great care shall be given to the quality of the water used. Bad boiler waters may cause corrosion, scale, foaming, overheating, and leaks. These result in loss of heat, in increased labor of attendance, in greater expenses for operation and repairs, in a shortened life of the plant, and in increased liability of explosion.

All natural waters are more or less corrosive on account of the presence of dissolved oxygen and carbonic acid, but waters which contain chlorides, nitrates, sulphates, etc., may, under certain conditions, become very corrosive. Swampy waters and some driven well-waters usually contain more free carbonic acid than ordinary river-waters. In some of the mining districts the only waters available are distinctly acid and are exceedingly corrosive. Magnesium chloride is corrosive, and that is largely why sea-water is so objectionable for use in boilers. It is often said that sodium chloride is not corrosive, but in the presence of silica

it may become so. Waters which are naturally only slightly corrosive may become very corrosive if allowed to concentrate in the boiler, and this they will do unless the boiler is occasionally emptied and cleaned. Corrosion is increased by mechanical action—that is, by movements of the boiler-sheet caused by expansion and contraction. It is most likely to occur at points where there is a tendency to movement and also along the water line. Local corrosion is frequently referred to as "pitting" or "grooving." Occasionally galvanic action may cause corrosion.

The formation of boiler scale is due to the precipitation from the water of the carbonates and sulphates of calcium and magnesium together with smaller amounts of other salts and of suspended matter. For each salt there are certain conditions which will cause precipitation. Calcium carbonate is quite insoluble after its extra molecule of carbonic acid has been driven off by heat. Calcium sulphate becomes almost insoluble above 250° F. (120° C.). Magnesium carbonate is changed to magnesium hydrate and precipitated. Boiler scale may also contain compounds of iron, silica, alumina, organic matter, etc., in endless variety of composition. Generally speaking, carbonate scales are soft and are more in the nature of a sludge or mud than true scale. Sulphates, on the other hand, form a hard scale, especially

when mixed with magnesia and silica. Calcium sulphate precipitates in a compact crystalline form, which can sometimes be removed only by hammering and chipping. It may happen that different kinds of scales occur in the same boiler, due to the different temperatures of the sheet in different parts and to the circulation of the water. The scale in the tubes is often different from that on the sheets.

Hard waters invariably form scale and comparatively soft waters may also do so if the boiler is used too long without being emptied. Concentrated soft waters are almost as bad in their effects as waters naturally hard. The greater the hardness, however, the more troublesome will the water be.

Foaming is caused chiefly by an excess of alkaline salts, which cause the water to form suds as if soap had been added. This makes a boiler unmanageable and affects the quality of the steam.

If grease is present in the water, the sludge or scale may become very sticky. In this condition it adheres tenaciously to the plates and causes overheating which usually occurs in spots. Scales themselves may cause the sheets to become overheated. They may also give rise to unnatural movements of the shell through expansion and contraction, and may thus ultimately cause leaks.

Financial Loss from Use of Hard Boiler Waters

Many estimates have been made to show how much the steam-maker loses by using a hard water instead of one satisfactory in character. Figures are often given showing the effect of boiler scales of different thickness on the loss of fuel. For example, it is sometimes stated that a boiler scale one-eighth inch thick will cause a loss of 20 per cent in the heat utilized from the fuel, while a scale three-eighths of an inch thick will cause a loss of 50 per cent. It is said that the resistance of sulphate scale to the passage of heat is from twenty to fifty times as great as that of an equal thickness of wrought iron, and that a film of grease one one-hundredth of an inch thick is equivalent in its heat-resisting powers to a boiler scale one-tenth of an inch thick, or to a steel plate ten inches thick. Figures of this character cannot be considered as very accurate, as they are based on insufficient data, yet they serve to illustrate the fact that boiler scales do cause very material losses of heat. Other figures have been given to show the reduced life of boilers by reason of corrosion or the presence of scale, and, while too inaccurate to deserve quotation, they help to illustrate the same truth, that bad boiler waters cost money to the steam user.

The most accurate figures perhaps, showing the excessive cost of hard waters as compared with soft waters, are those which have been compiled by some of the Western railroads. They are based upon data relating to the use of water in locomotives before and after the installation of water-softening plants. The following table, based on a report of the Chicago and Northwestern Railway, is an excellent illustration of this:

TABLE 19.

COMPARISON SHOWING THE EFFECT OF WATER-SOFTENING AT SEVENTEEN STATIONS ON THE CHICAGO AND NORTHWESTERN RAILROAD.

(The two years represent the condition before and after softening.)

	1902	1903
Ton-mileage, in million ton-miles	2934	3154
Increase in ton-mileage		230 (7.5%)
Pounds of coal per 100 ton-miles	28.7	27.5
Saving in coal, pounds per 100 ton-miles		1.2
Saving in coal (at \$3 per ton for 3,000 million ton-miles)		\$30,000
Average assignment of engines (83% of them were in constant service both years)	159	154
Saving in assignment of engines		5
Saving in engines (10% interest and depreciation on cost of five engines at \$10,000 each)		\$5,000

Number of boiler-makers employed	36	23	
Number of helpers employed	42	30	
Total number of laborers on boilers	78	58	
Saving in laborers		20	(26%)
Saving in wages of boiler-makers and helpers		$7,700	
Saving in materials for boiler-repairs	Not estimated, but known to be large		
Boiler failures from leaky flues	544	99	
Boiler failures from leaky fire-boxes	33	20	
Boiler failures from leaky arch-tubes	6	1	
Total	583	120	
Reduction in number of boiler failures		463	(79%)
Estimated saving to the road, all causes		$75,000	

The figures show a decided saving in coal, in labor, and materials for repairs on engines, etc. One of the most important advantages to the road was the decrease in the number of engine failures. This means more to a railroad man than to an outsider, as it involves losses due to the stopping of many trains, the derangement of time-tables, charges for perishable freight, overtime, etc. The Committee on Water Service of the American Railway Engineering and Maintenance of Way Association summed up the benefits of the use of soft water to the railroads as follows:

1. Fewer boiler failures due to leaks.

2. Longer life of flues and fire-box sheets.

3. Reduced cost of labor for repairs and washing boilers.

4. Increased locomotive mileage between stoppings.

5. Increased ton-mileage per pound of coal consumed.

6. Decreased number of locomotives in service.

7. Better feeling among the men due to fewer failures and shorter time of the road.

8. Less expense in cost of overtime and delayed time.

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